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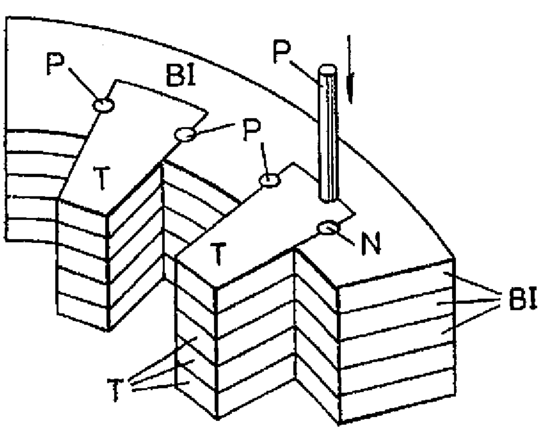
(54) **Title:** COMPOSITE STATOR



(57) **Abstract:** A segment for a stator comprising a back iron portion BI and one or more teeth T characterised in that the teeth are cut separately from the back iron portion and are joined with the back iron portion and the teeth and back iron have different magnetic properties and or magnetic orientation with respect to each other.

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COMPOSITE STATOR

This invention relates to stators as commonly used in large scale electrical machines. More particularly, the invention provides an apparatus and method which provides improved efficiency of operation of such machines.

Large electrical machines such as alternators (generators) and motors comprise magnetic flux carrying cores, typically of electrical steels. Rotating machines use laminations which, in large machines, may be made up of segments cut so as to incorporate teeth which are enclosed by windings and so-called back iron which conducts magnetic flux between the stator teeth. Such an arrangement is illustrated in Figure 1.

Because of the bi-directionality of flux movement it is usual to manufacture stator segments from non-oriented electrical steel, since if grain oriented steel is chosen, the flux must pass into a magnetically less favourable direction of the grain oriented steel for part of its journey.

The properties of non-oriented steel are less favourable than those for the magnetically most favourable or "best direction" within a grain oriented electrical steel. In order to exploit this much enhanced 'best direction', the less favourable direction in grain oriented steel (which has generally worse magnetic properties than a non-oriented steel) may be tolerated for part of the segment. Necessarily, such an arrangement is a severe compromise as the magnetic permeability and power loss varies hugely between the 'best' and 'orthogonal (or worst)' directions of grain oriented steel.

The present invention aims to provide a stator which suffers less loss and as such is more efficient in operation.

In accordance with a first aspect the present invention provides a segment for a stator comprising a back iron portion and one or more teeth characterised in that the teeth are cut separately from the back iron portion and are joined with the back iron

portion and the teeth and back iron have different orientation with regard favoured magnetic direction with respect to each other.

Normally the favoured magnetic direction for any gain oriented electrical grade steel will be the direction in which the steel was rolled during manufacture, this is sometimes also referred to as the "longitudinal" direction of the steel or the article (such as a tooth or back iron portion) made from the steel. In grain oriented steel, this direction will be far more dominant than that seen for a non-oriented steel. However, for non-oriented steel there may be some anisotropy that will give more favourable magnetic properties in the longitudinal direction.

It is to be understood that whilst reference is made to a segment for a stator in the description of the invention, a "segment" could in fact comprise a complete ring of back iron (or a "back iron portion") cut from a single sheet. Desirably, in such an embodiment of the invention, the back iron would be cut from a sheet of non-oriented material.

. The invention aims to utilise optimum materials (from a technical or an economic point of view) in both teeth and back iron. Desirably, best direction magnetic properties for both the teeth and back iron of stator is achieved, however this can inflate production costs to a level which is undesirable for some applications. In an alternative and more cost effective option, a combination of a good non-oriented steel in the teeth and a lower cost/quality non-oriented steel in the back iron may be used. It is to be noted, of course, that there may be circumstances where it is desirable to have a relatively higher grade material in the back iron with respect to the teeth, such arrangements are also possible in accordance with the invention. In another alternative, mixed grades of materials may be utilised, for example grain oriented material for the teeth and non-oriented grades of steel for the back iron portion. It is to be appreciated that, since the invention utilises materials and magnetic orientations which optimise the flow of flux for a particular application of the stator, the invention permits a reduction in the total quantities of material used and thereby reduces waste material. Typically, by utilizing the invention, a considerable reduction in the size of the back iron needed

can be achieved, this has not only waste saving advantages but also space saving advantages, allowing more flexibility in factory floor layouts where these machines are incorporated.

By suitable choice of cutting methods, both teeth and back iron portions can be provided from grain oriented strip in ways that minimise waste of material. Furthermore, and desirably, mixed grades of materials are joined to allow the convenient transference of flux, for example by laser welding, press fit joining or bonding by other well known techniques, of either individual segments, or laminated stacks of segments, by use of various shaped joints. The shape of the joint may be chosen so as to optimise the transfer between tooth and back iron whilst reducing the effects of rotational flux.

Suitable joint shapes may include any shape where the base of a tooth is enlarged for receiving in a narrowing recess of the back iron. It is postulated that such arrangements would assist in reducing losses as flux flow between the favoured magnetic direction of a tooth and that of the back iron. In addition, such arrangements can provide for an improved rigidity of the join between the back iron and the teeth. It is to be understood that arrangements where a protrusion from the back iron is received into a recess of a tooth is a possibility not to be excluded from the scope of the invention as defined herein, however, it is expected that such arrangements may have inferior joint strength.

Examples of suitable joint shapes, whether they be for a tooth base received in a recess in the back iron, or a protrusion of back iron for receipt in a recess in the tooth, include, but are not strictly limited to the following; shapes with rounded or radiused edges including substantially circular, oval or ellipsoidal shapes; shapes which are substantially symmetrical about an axis substantially in line with the favoured magnetic direction of the tooth, such as dovetails and fir tree joints. Again it is to be understood that any joint shape which permits the interlocking of the tooth and back iron may be used, furthermore two substantially planar surfaces of a tooth and back iron may also provide the interface for a join. Desirably, in the latter case, the joint is

further secured by adhesion, physical bonding or some form of welding. Interlocking shapes may, optionally be bonded, but equally may rely simply on their interlocking arrangement for security of the joint. Any suitable chemical or physical bonding methods may be used to secure a joint, including but not limited to welding processes such as TIG welding or laser welding. Alternatively, the surfaces may be bonded by a chemical adhesive.

Teeth and back iron blanks, which have been selected for optimum orientation, may be formed into a composite blank. This may be subsequently stamped or laser cut etc into the final shape of the segment. A segment so manufactured is considered to comprise a segment in accordance with the present invention as claimed in the appended claims.

Without limitation, the cutting of steel to form such joints may be achieved by conventional stamping, punch or die cutting techniques or by the preparation of lamination stacks of segments by techniques such as wire spark cutting, laser cutting, e-beam or water jet cutting.

Optionally, a coating (or partial coating) or small object such as a locking pin of an electrically insulating material, may be provided between the joining surfaces of the back iron and the teeth. This may assist in the reduction of eddy currents in the region surrounding the joint.

The inventors have found that by applying the principles of the invention, overall reductions of power loss in a machine core of up to 69% may be achieved. The invention can be used to improve the permeability of a system, raising the available magnetic flux density and torque, enabling less copper to be used in the magnetising windings and a lower weight of core metal employed to procure good machine performance. There is, of course associated cost savings with these advantages. Reduction in the magnetic reluctance of the stator, and hence the machine, magnetic circuit gives the machine a superior electromagnetic continuity (sometimes referred to as "electromagnetic stiffness") and lower leakage reactance.

Figure 1 shows a stator as is known from the prior art.

Figures 2a and 2b show views of a segment for a stator in accordance with the invention.

Figure 3 shows an embodiment of a stator according to the invention.

Figure 4 shows a testing apparatus as used to perform the examples and comparisons with prior art described below.

As can be seen in Figure 1, the stator consists of laminations which make up a back iron and teeth. The laminations are typically segmented and each segment is cut to form a back iron portion and tooth portion in a single piece. The back iron is relatively large. It will be appreciated that in this arrangement, the magnetic flux runs parallel to the length of a tooth prior to turning through 90° to run along the back iron.

As can be seen from Figures 2a and 2b, the segment of the present invention is comprised of a number of pieces joined together. A first piece BI forms the back iron portion and a plurality of additional pieces T form the teeth. The teeth and back iron pieces are cut to have reciprocally shaped surfaces for joining together. In the Figure, the end of each tooth piece is shaped at its base to fan outwards into a reciprocally shaped recess in the back iron. In this arrangement, rather than abruptly turning through 90 degrees, the magnetic flux of the system is gently bent by the curvature of the fanned base and into alignment with the favoured magnetic direction of the back iron piece.

As can be seen from Figure 3, a stator (shown in a perspective cross section) comprises a plurality of back iron (BI) portions and teeth (T) stacked to form laminations. In the adjoining surfaces of both the back iron portion (BI) and the teeth (T), are provided pairs of opposing notches (N). The notches are shaped to receive securing pins, P which, desirably are made from insulating materials. This arrangement facilitates the use of considerably simpler shaped teeth and back iron

blanks. This arrangement also helps reduce eddy currents which may otherwise be greater in the joint area.

Examples and Comparisons with prior art

The behaviour of various composite stators was evaluated using a purpose built laboratory test frame as shown in Figure 3. A standard loss testing system, comprising induction (B) and magnetising field (H) sensing coils, was used for loss measurement. Various tooth and back iron stator shapes were precision cut by a spark-wire method. Figure 2 shows the shape and size of a test assembly of shaped laminations. Sample packs A and B are 'teeth' able to be precisely located into the 'back iron' sample packs C and D. Sample packs E and F are simply flux closure yokes. Excitation and induction sensing windings are located so as to enwrap the teeth. An air gap (g) was introduced between the tooth ends which was able to be varied.

No waveform control or air flux compensation was employed since none would be used in a commercial machine. In all cases, the side flux closure material employed was 'with' direction grain oriented electrical steel.

The mechanical stiffness of keyed in teeth was noted to be very good. It is feasible therefore that a commercial stator core could be constructed in this manner without the need for welding.

Experiments carried out to note the effect of tooth to back iron lamination mismatch of facing edges due to differences in tooth and back iron steel thickness showed that any effects were minor, being outweighed by the main air gap reluctance.

The performance of various composite stator arrangements will now be described by the following examples. Examples 1-4 relate to composites of grain oriented (GO) electrical steel whilst examples 5- 9 relate to composites of grain oriented and non-oriented (NO) steels. Other terminology to note in the tables is L for longitudinal (i.e. in parallel with rolling direction of steel), T for transverse (i.e.

orthogonal to rolling direction of steel) and air gap (g).

Example 1

In this case, which is not according to the invention, the composite stator comprised grain oriented 'longitudinal (L)' teeth i.e. teeth cut in the rolling direction of the strip, and grain oriented 'transverse (T)' back iron i.e. field direction in the direction 90° to the rolling direction of the strip. This is the conventional way in which grain oriented steel would be used in this stator application.

Air gaps (g) between the teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Table 1. An air gap of 0.75mm was considered most realistic for the set up size and it can be seen that a nominal power loss of 75 arbitrary units was noted.

Specific apparent power, also termed as VA values are indicated in Table 2 where it can be seen that for the conventional use of GO material, VA values noted were 20.1 arbitrary units for the 0.75 mm gap.

Example 2

In this case, according to the invention, the composite stator comprised 'L' grain oriented teeth and 'T' grain oriented back iron. Air gaps between the teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Tables 1,2.

This arrangement resulted in a power loss of 52 units (i.e. 69% of the power loss of the conventional arrangement indicated in Example 1). The VA values are largely air-gap driven for a given set up and high permeability teeth gives low VA values independent of the back iron steel. In this case the VA values were reduced to 19.7 arbitrary units compared to the 20.1 units of Example 1. Clearly this arrangement is very beneficial to performance.

Table 1 Loss Data (arbitrary units for comparison) at $B_{max} =$ 1.8T, 50Hz

	Example 1*		Example 2		Example 3		Example 4	
Air Gap (mm)	GO Teeth L	GO BI T	GO Teeth L	GO BI L	GO Teeth T	GO BI L	GO Teeth T	GO BI T
0	60		48		78		98	
0.35 mm	72		57		83		100	
0.75 mm	75		52		87		130	

*Conventional use of GO

Table 2 VA Data (arbitrary units for comparison) at $B_{max} =$ 1.8T, 50Hz

	Example 1*		Example 2		Example 3		Example 4	
Air Gap (mm)	GO Teeth L	GO BI T	GO Teeth L	GO BI L	GO Teeth T	GO BI L	GO Teeth T	GO BI T
0	5.15		5.15		29.8		31.4	
0.35 mm	12.9		13.3		38.6		38.6	
0.75 mm	20.1		19.7		46.7		>50	

* Conventional use of GO

Example 3

In this case, not according to the invention and also not the normal orientation for use of grain oriented material, the composite stator comprised grain oriented 'T' teeth and grain oriented 'L' back iron. Air gaps between the teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Tables 1,2.

In this case the power loss of the core increased to 87 arbitrary units and the VA values increased to 46.7 arbitrary units. Clearly this is not an ideal configuration for composite stator fabrication.

Example 4

In this case, in principle according to the invention but an extremely unfavourable way of applying the invention, the composite stator comprised grain oriented 'T' teeth and grain oriented 'T' back iron. Air gaps between the teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Table 1,2. In this case the loss of the core increased to 130 arbitrary units.

The next series of examples compares the effect of composites of GO and NO material in stator cores.

Example 5

In this case the composite stator comprised GO 'L' teeth and GO 'T' back iron. Air gaps between the model teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Table 3,4. This is the conventional use of GO material.

A loss value of 75 (arbitrary units) was noted and the VA value was 20.12 (arbitrary units). This is the configuration against which the other configurations are compared.

Table 3 Loss Data (arbitrary units for comparison) at B_{max} = 1.8T, 50 Hz

	Example 5*		Example 6		Example 7		Example 8		Example 9	
Air Gap (mm)	GO Teeth L	GO BI T	NO Teeth L	NO BI L	GO Teeth L	GO BI L	GO Teeth L	NO BI L	NO Teeth T	NO BI L
0	60		63		48		50		78	
0.35 mm	72		68		57		54		79	
0.75 mm	75		77		52		58		93	

* Conventional use of GO

Table 4 VA Data (arbitrary units for comparison) at B_{max} = 1.8T, 50 Hz

	Example 5*	Example 6	Example 7	Example 8	Example 9
Air Gap (mm)	GO Teeth L / GO BI T	NO Teeth L / NO BI L	GO Teeth L / GO BI L	GO Teeth L / NO BI L	NO Teeth T / NO BI L
Nil	5.15	24.28	5.15	38.64	31.95
0.35 mm	12.88	29.82	13.28	12.07	37.06
0.75 mm	20.12	38.34	19.72	17.71	42.6

* Conventional use of GO

Example 6

In this case, according to the invention the composite stator comprised NO teeth and NO back iron (all 'L'). Air gaps between the teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Table 3,4. .

It can be seen that a loss value of 77 arbitrary was achieved (compared to 75 for example 5) and a VA value of 38.34 arbitrary units was noted compared to 20.12 (for example 5). The loss values have therefore remained similar to example 5 but the VA levels are higher.

Example 7

In this case, according to the invention the composite stator comprised GO 'L' teeth and GO 'L' back iron. Air gaps between the teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Table 3,4.

It can be seen that a loss value of 52 arbitrary units was achieved, the lowest noted in the composites evaluated, and that VA values were 19.72 arbitrary units.

Example 8

In this case, according to the invention, the composite stator comprised GO with teeth and NO with back iron. Air gaps between the teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Table 3,4.

It can be seen that a loss value of 58 arbitrary units was achieved, and that VA values were 17.71 arbitrary units, the lowest noted for the various composites evaluated

Example 9

In this case, in principle according to invention, but very unfavourable use, the composite stator comprised NO 'T' teeth and NO 'L' back iron. Air gaps between the model teeth in the test system of 0, 0.35mm and 0.75mm were evaluated. The results of magnetic measurements are given in Table 3,4

It can be seen that a loss value of 93 arbitrary was noted and a VA value of 42.6 arbitrary units was noted, this configuration giving a very poor performance.

CLAIMS:

1. A segment for a stator comprising a back iron portion and one or more teeth characterised in that the teeth are cut separately from the back iron portion and are joined with the back iron portion and the teeth and back iron have different magnetic properties and/or magnetic orientation with regard favoured magnetic direction with respect to each other.

2. A segment for a stator as claimed in claim 1 characterised in that the shape of the join between a tooth and the back iron portion is selected to provide reduced disruption or loss of magnetic flux flowing between the teeth and the back iron portion.

3. A segment for a stator as claimed in claim 1 or claim 2 characterised in that the teeth and back iron comprise steels of respectively different grades of electrical steels.

4. A segment as claimed in any preceding claim wherein the back iron portion is stamped, punched or cut from a strip using a method such as laser, wire erosion, water jet or electron beam cutting.

5. A segment as claimed in any preceding claim characterised in that the back iron portion and the teeth are both made from grain oriented electrical steels.

6. A segment as claimed in claim 5 wherein the grain is orientated substantially longitudinal for the teeth and the back iron portion.

7. A segment as claimed in any of claims 1 to 4 wherein the teeth comprise a grain oriented electrical steel, the grain orientation being substantially longitudinal in the teeth.

8. A segment as claimed in claim 7 wherein the back iron portion comprises a non-oriented electrical grade steel.

9. A segment as claimed in any of claims 1 to 4 wherein the back iron portion and the teeth each comprises non-oriented electrical grade steels.

10. A segment as claimed in claim 9 wherein either or both of the back iron portion and the teeth comprise longitudinal non-oriented grade steels.

11. A segment as claimed in any preceding claim wherein the teeth are joined to the back iron portion by fitting of protrusions into notches or recesses in the back iron portion or by fitting of protrusions on the back iron portion into recesses of the teeth.

12. A segment as claimed in claim in any preceding claim wherein the joints are welded by a method such as laser welding or TIG welding.

13. A segment as claimed in any preceding claim wherein the segment is at least partially coated with an electrical steel insulation in order to improve the surface insulation resistance of the segment.

14. A segment as claimed in any preceding claim wherein the surfaces to be joined are ground prior to joining to remove any burrs or protruding material.

15. A segment as claimed in any preceding claim wherein the shape of the joint between the back iron and teeth is configured such that the teeth are securely locked in the radial and tangential direction of the stator core.

16. A segment as claimed in any preceding claim wherein a thin electrical insulation layer is provided between the back iron and the teeth whereby to avoid or minimise eddy currents in the region of the joint.

17. A segment as claimed in claim 16 wherein the insulation layer is a coating applied to the surface of the back iron portion which forms the join with the teeth.

18. A stator comprising a plurality of segments as claimed in any preceding claim.

19. A stator as claimed in claim 18 wherein multiples of segments are stacked to form a laminated stator.

20. A stator as claimed in claim 19 wherein the back iron portions are laminated separately to the teeth, and optionally in an overlapping configuration.

21. A stator as claimed in claim 20 wherein the teeth segments are joined with the back iron segments after lamination.

22. A stator as claimed in any of claims 18 to 21 wherein the back iron portion comprises a single, complete ring cut from a single piece of material.

23. A stator as claimed in claim 22 wherein outer diameter of the stator is larger than 1300 mm.

24. A method for fabricating a stator as claimed in any of claims 18 to 23 comprising laminating a plurality of the segments to form a ring comprising an outer diameter consisting of back iron portions and a plurality of teeth projecting inwardly radially of the back iron portion.

25. A method as claimed in claim 24, where the teeth are individually fitted into a stcked asembly of back iron portion laminations.

26. A method as claimed in claims 24 or 25 wherein a pre-laminated stack of teeth are fitted into a stacked assembly of back iron portion laminations.

27. A method as claimed in any of claims 24 to 26, wherein the height of the stack of teeth is substantially the same as the height of the stack of back iron laminations.

28. A method as claimed in any of claims 24 to 27 where the laminated segments are secured together by means of interlocks between the laminations.

29. A method as claimed in any of claims 24 to 28 wherein the stack of teeth laminations is made secure by means of adhesive bonding.

30. A method as claimed in claim 24-29, wherein the teeth and back iron portion are secured together by means of a locking device, such as a pin, made of an electrically insulating material, the locking device being inserted in the joint between the teeth and back iron so that it locks the laminations in place.

31. A method as claimed in any of claims 24 to 30 in which materials selected for optimum tooth and back iron orientation are formed into a composite blank and composite segments are cut, stamped pressed or otherwise provided from the composite blank.

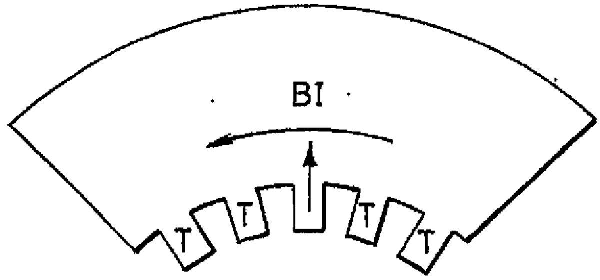

FIG. 1

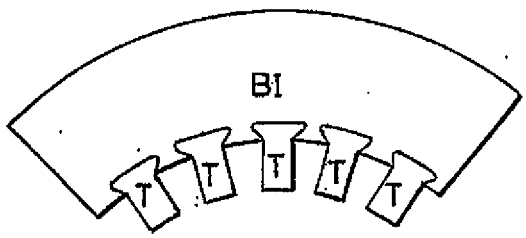

FIG. 2a

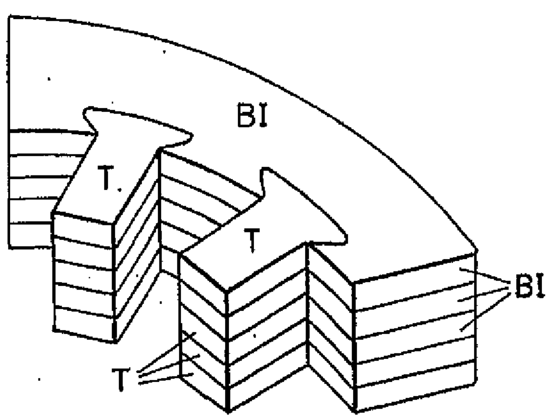

FIG. 2b

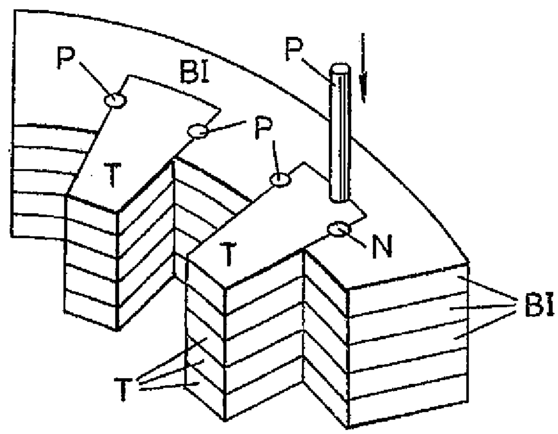

FIG. 3

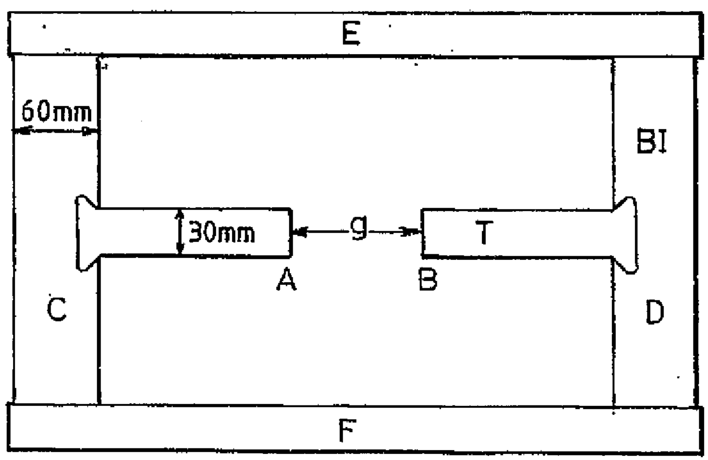

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/05517

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02K1/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95 12912 A (STRIDSBERG INNOVATION AB ;STRIDSBERG LENNART (SE)) 11 May 1995 (1995-05-11)	1-4, 11-31
Y	the whole document	5-10
Y	DE 197 28 172 A (HILL WOLFGANG) 28 January 1999 (1999-01-28) column 5, line 43 -column 5, line 63	5-10

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
17 April 2002	24/04/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ramos, H

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
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